Potential Ultracapacitor Roles for Hybrid Electric Vehicles

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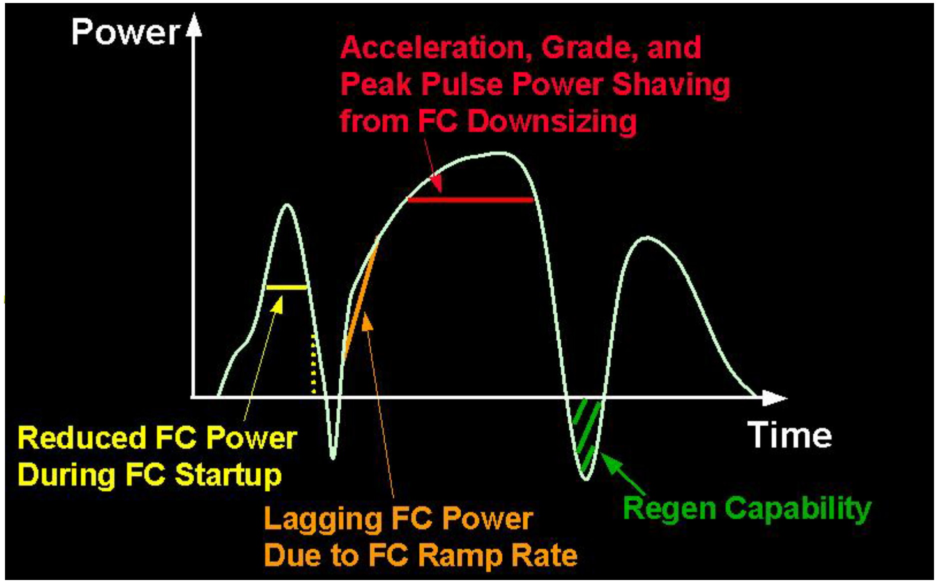
Outline

- **Fuel Cell Hybrid Vehicle Simulations**
- Dual-Source Battery/Electrochemical-Double-Layer-Capacitor (EDLC) Evaluation for Component Specialization.
- Conclusions

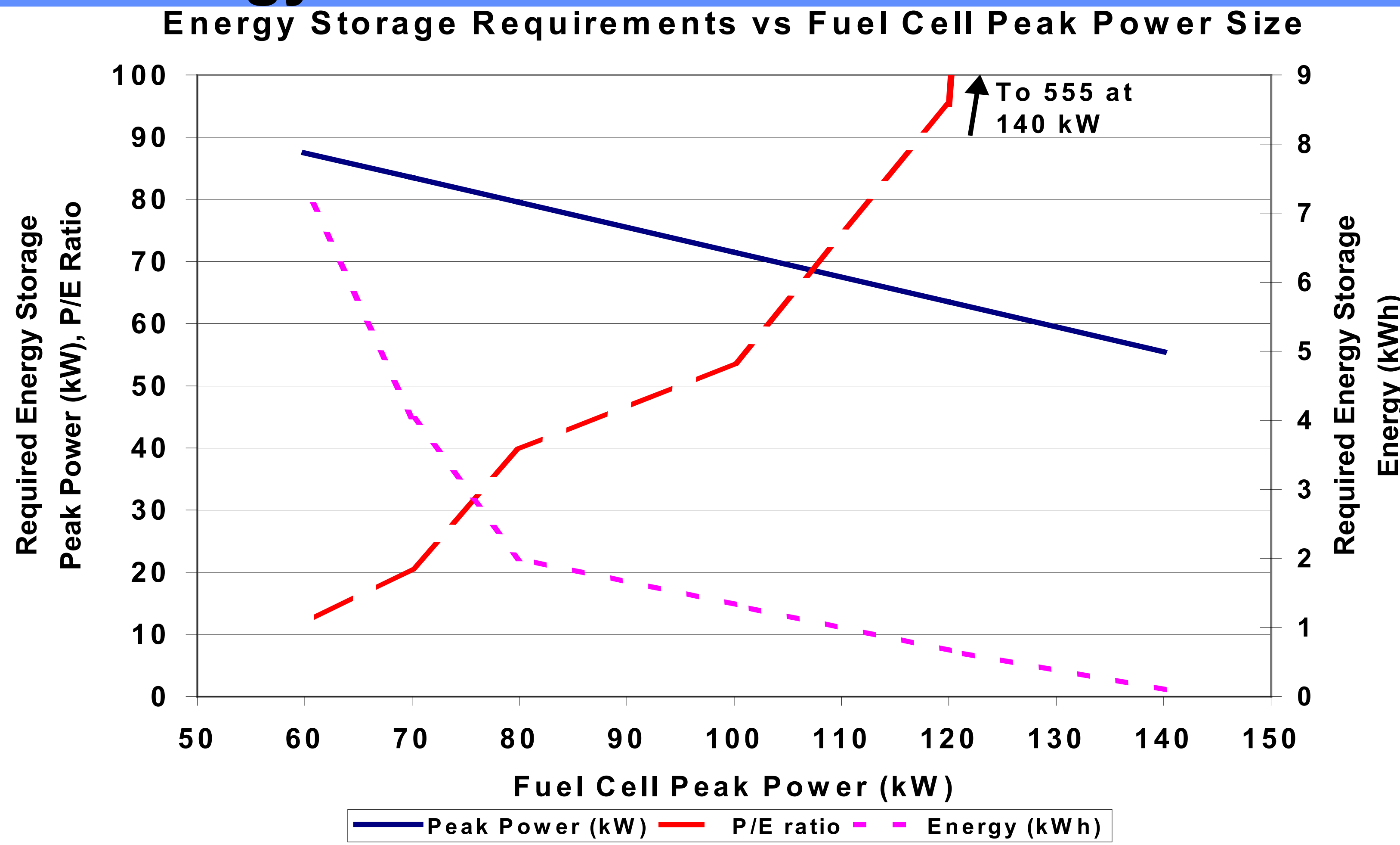
Performance Requirements Dictate Peak and Steady-State Loads

- Vehicle and Performance Requirements
  - Mid-size SUV (Explorer, Durango, Blazer)
  - Target 0-60 mph acceleration in 10.2 s
  - 65 mph at grade of 6.5% continuous (at least 20 minutes)
  - Top speed of 100 mph
- Final Power Requirements (based on simulations)
  - 140kW peak power for 0-60 mph acceleration
  - Minimum (fuel cell) power of 80kW for maintaining speed at 6.5% grade

Assumption Description	Units	mid-size SUV
0-60 mph	*s*	10.2
Top Speed	*mph*	100
Grade @ 65mph for 20min. at Curb Mass + 408kg	*%*	>=6.5
Drive Cycle Tolerance	*mph*	<=2

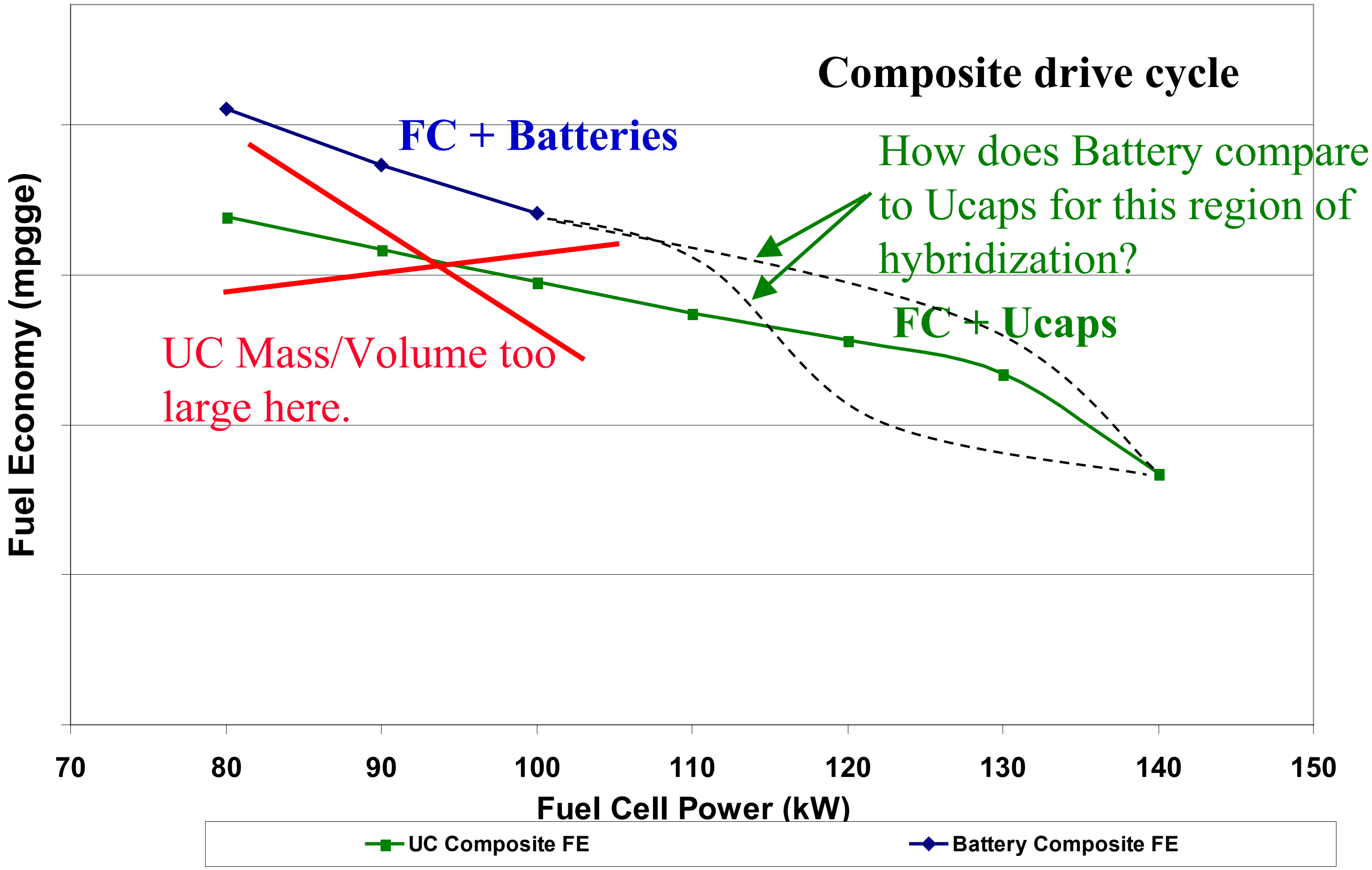


Required P/E Ratio Suggests Certain Energy Sources for MidSize SUV

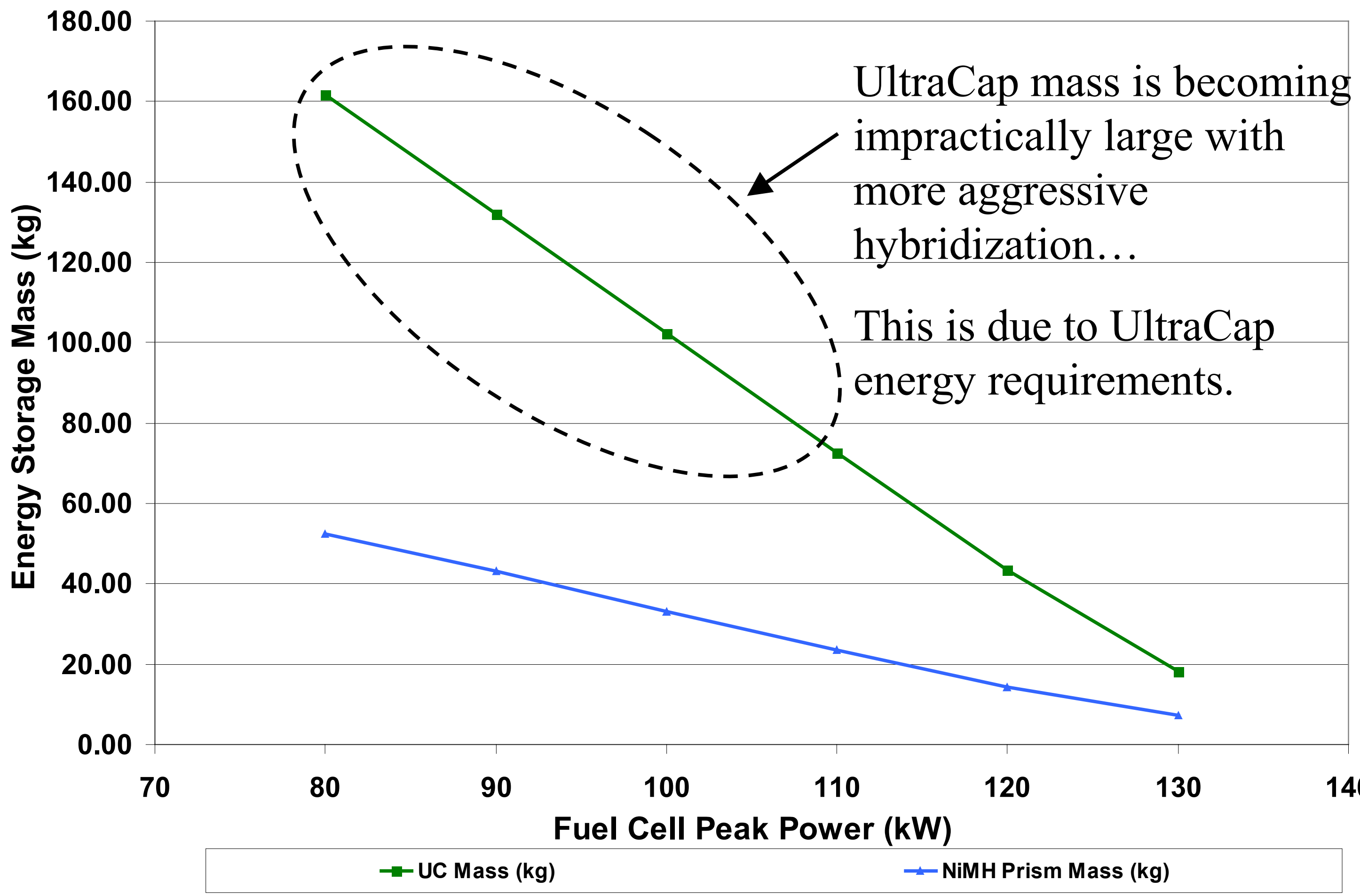


UltraCapacitor vs. Battery Hybridization for MidSize SUV

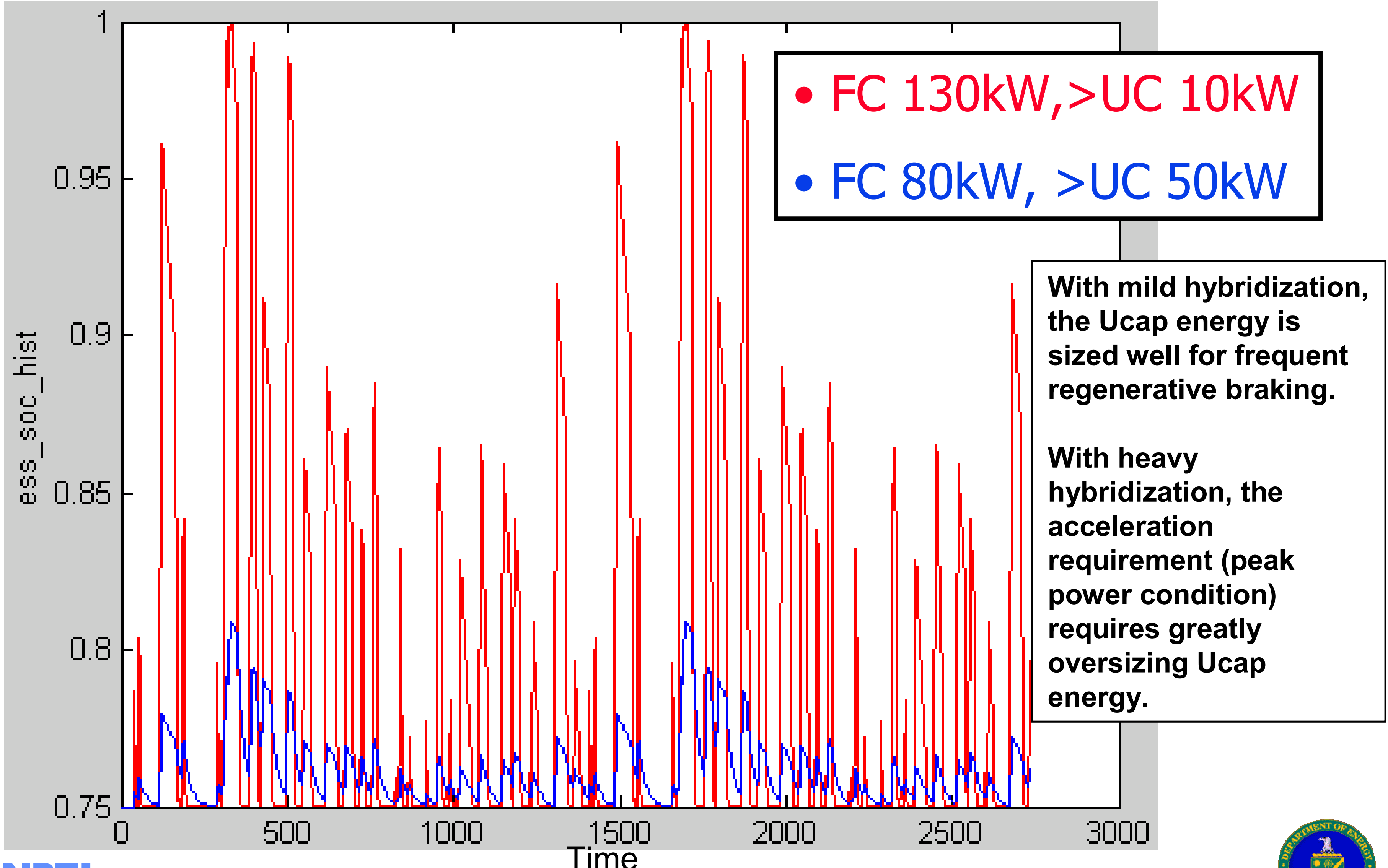
- Fuel economy benefit for Ucaps quickly tapers off due to inability to provide energy needs efficiently (gravimetrically and volumetrically)
- Fuel economy benefit for batteries increases until the gradeability limit (80kW)



Hybridization Mass Requirements for MidSize SUV



EDLC Operational Details – Mild vs. Heavy Hybridization



With mild hybridization, the Ucap energy is sized well for frequent regenerative braking.

With heavy hybridization, the acceleration requirement (peak power condition) requires greatly oversizing Ucap energy.

Outline

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- **Dual-Source Battery/EDLC Evaluation for Component Specialization.**
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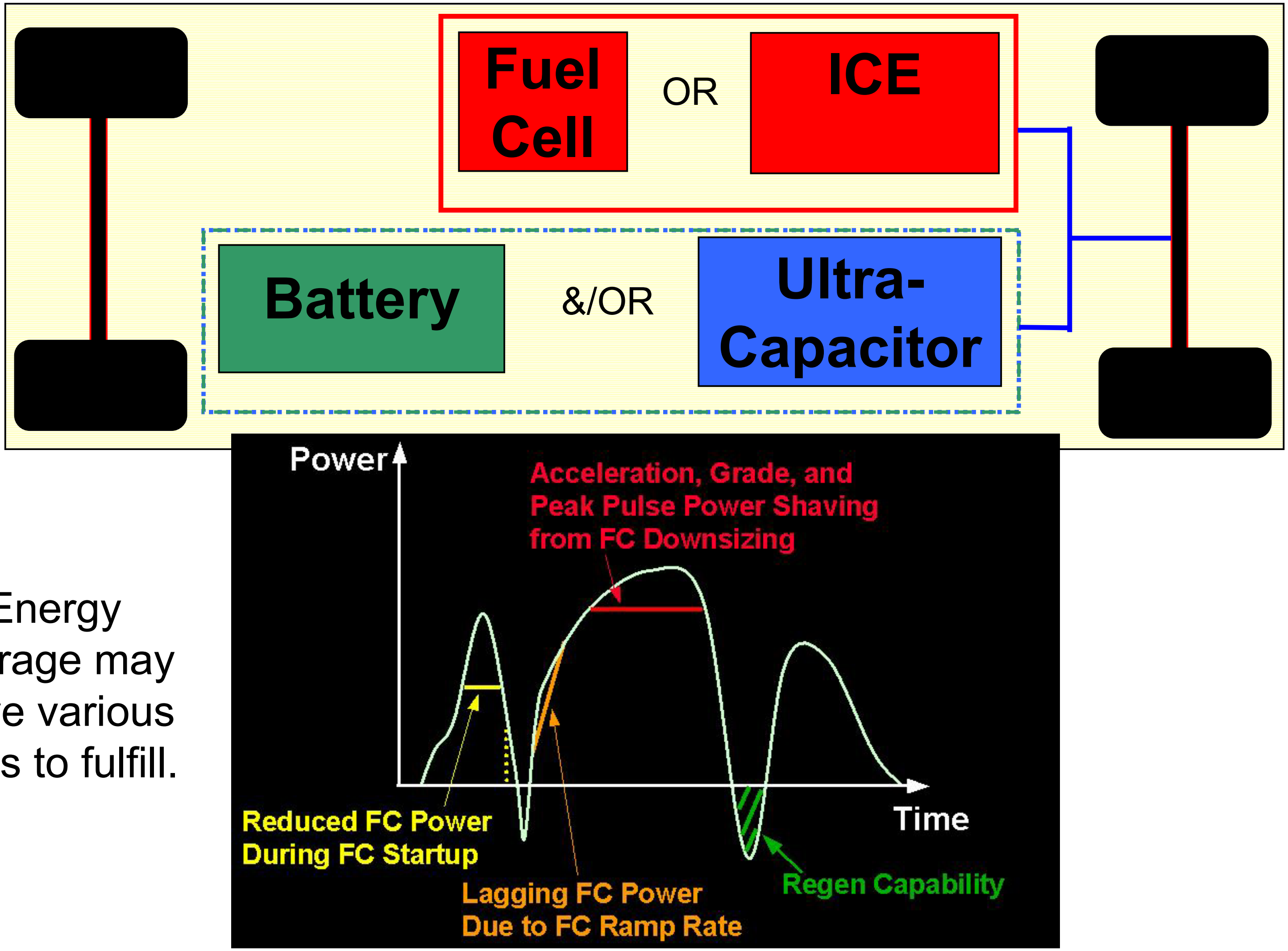
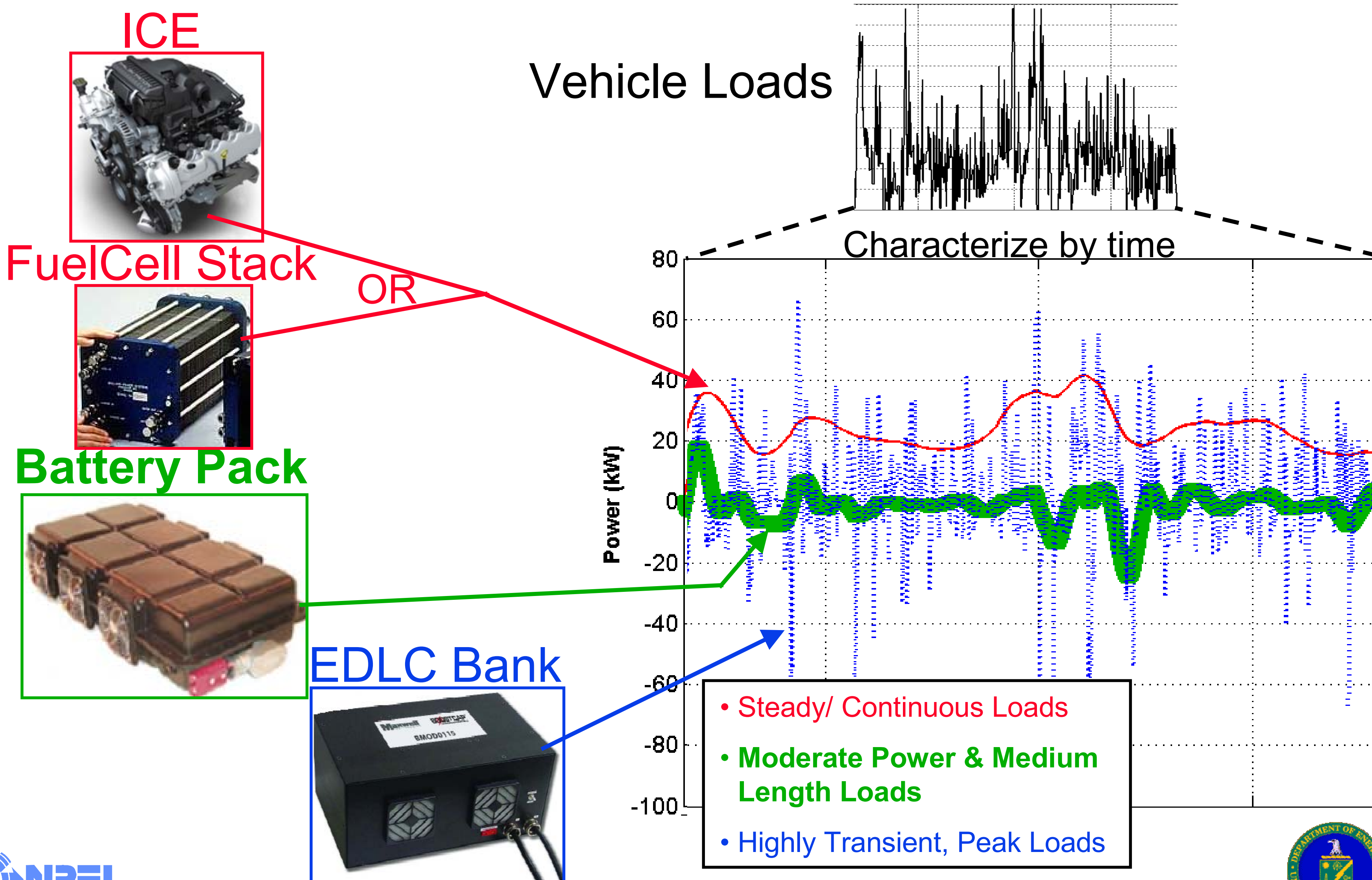
Dual-Source Hybridization Concept

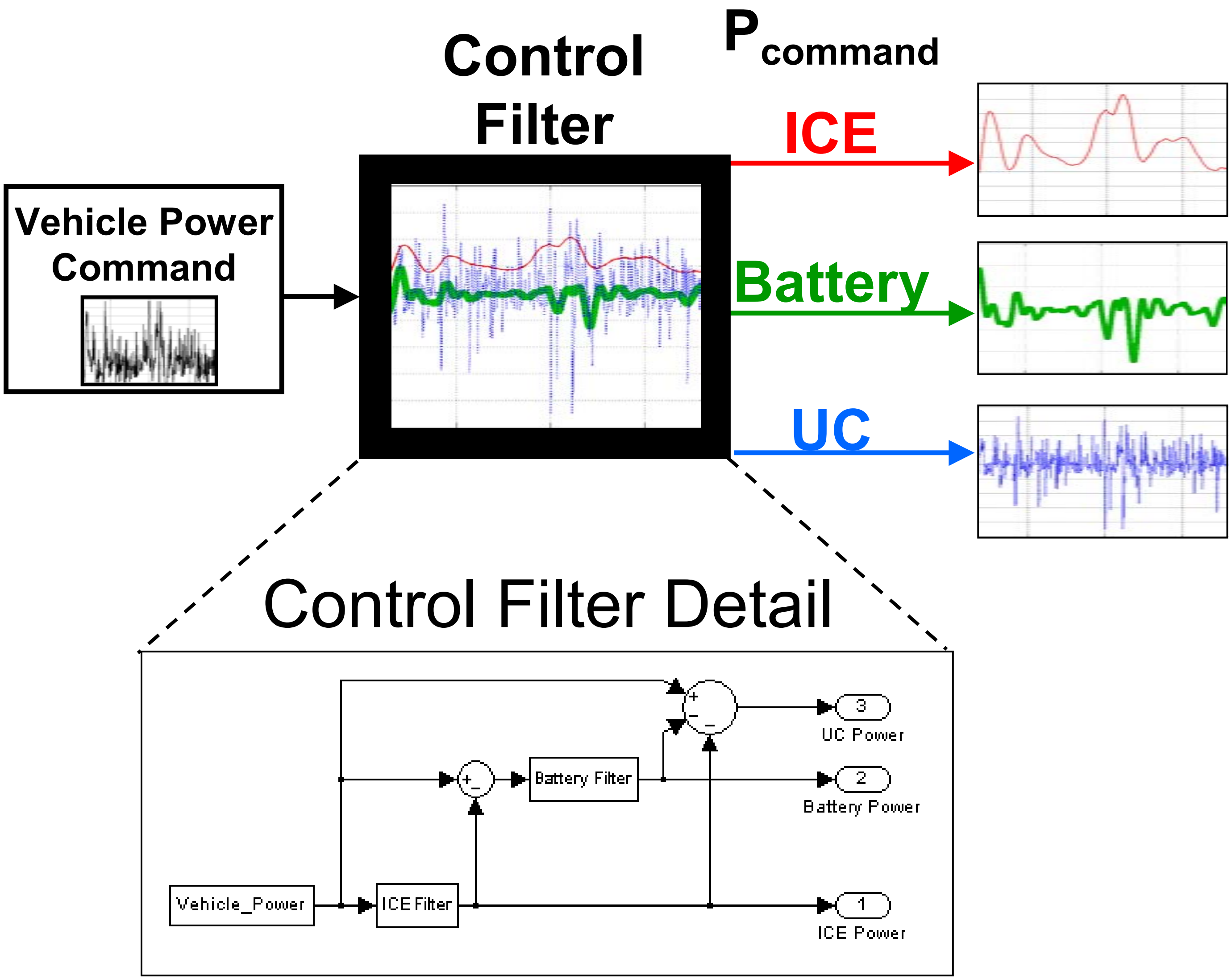


Energy Storage may have various roles to fulfill.

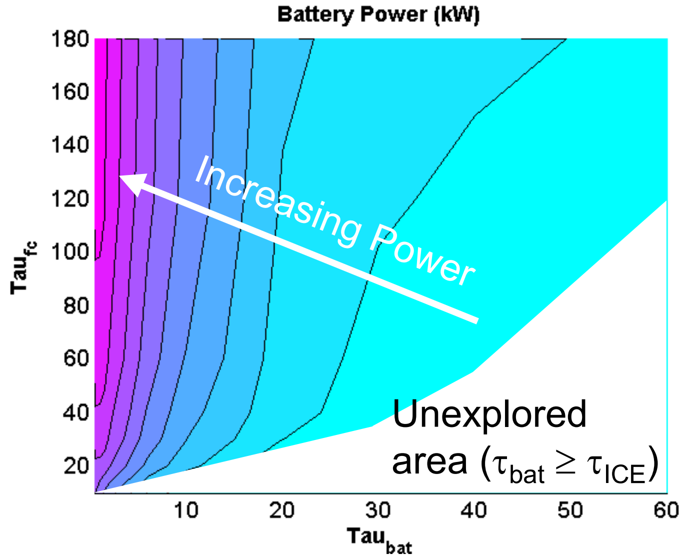
Hybridization Allows Opportunity for Sourcing Various Loads with Multiple Sources

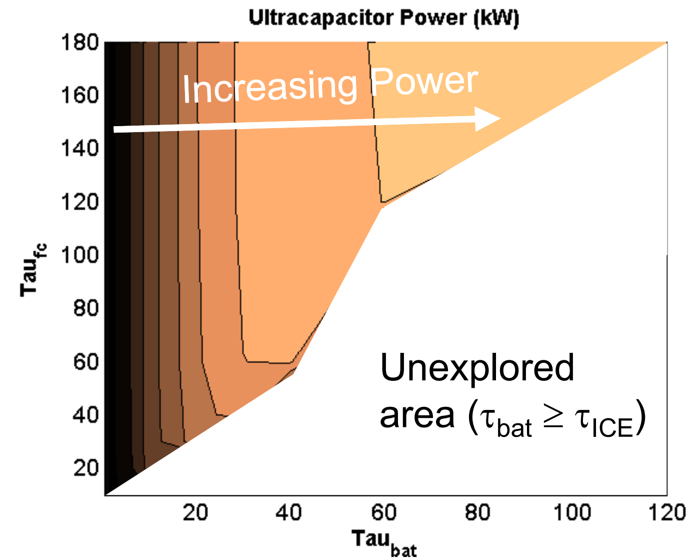


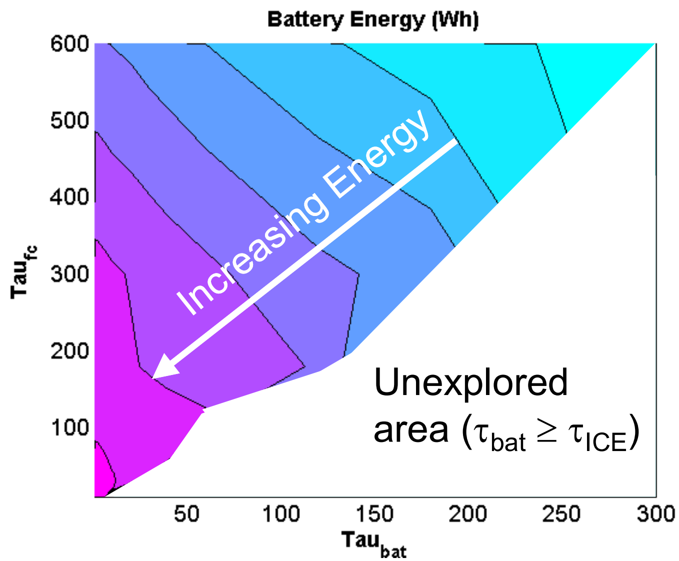
Parametric Evaluation Tool

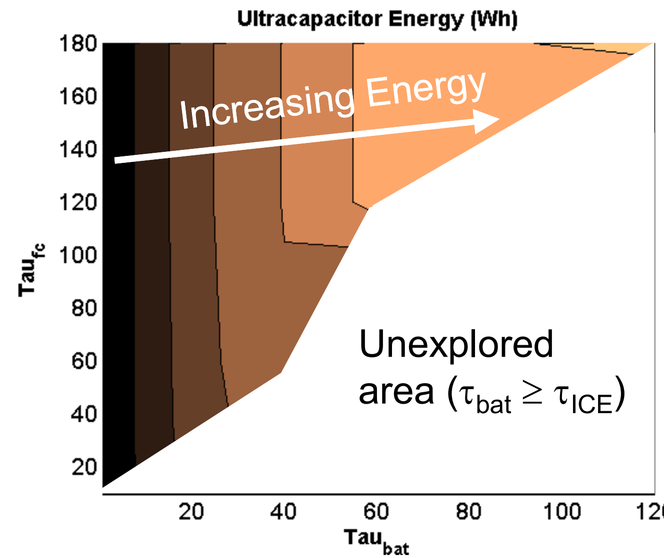


Component Power/Energy Requirements as a Function of Filter Time Constant (Tau)



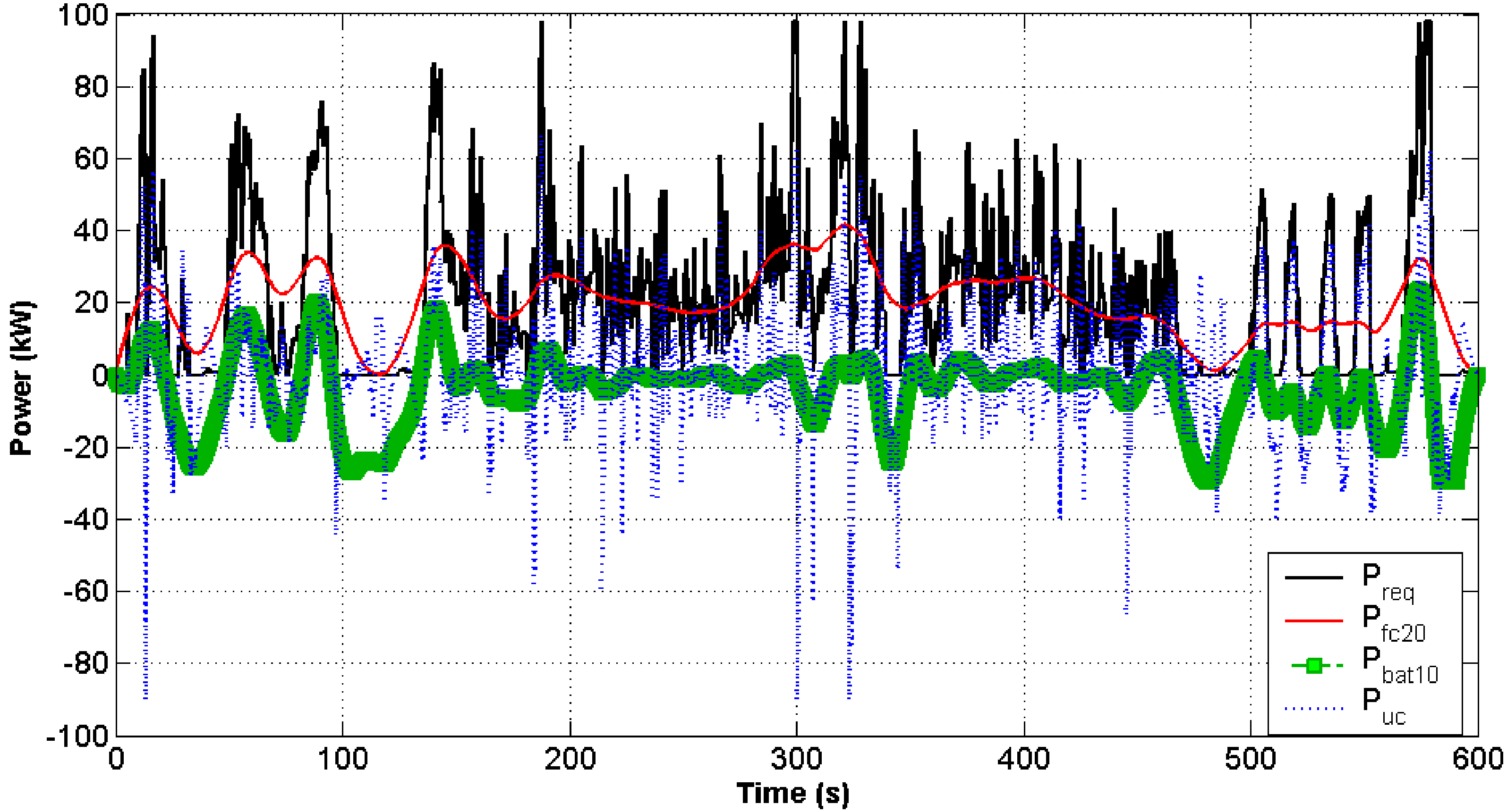




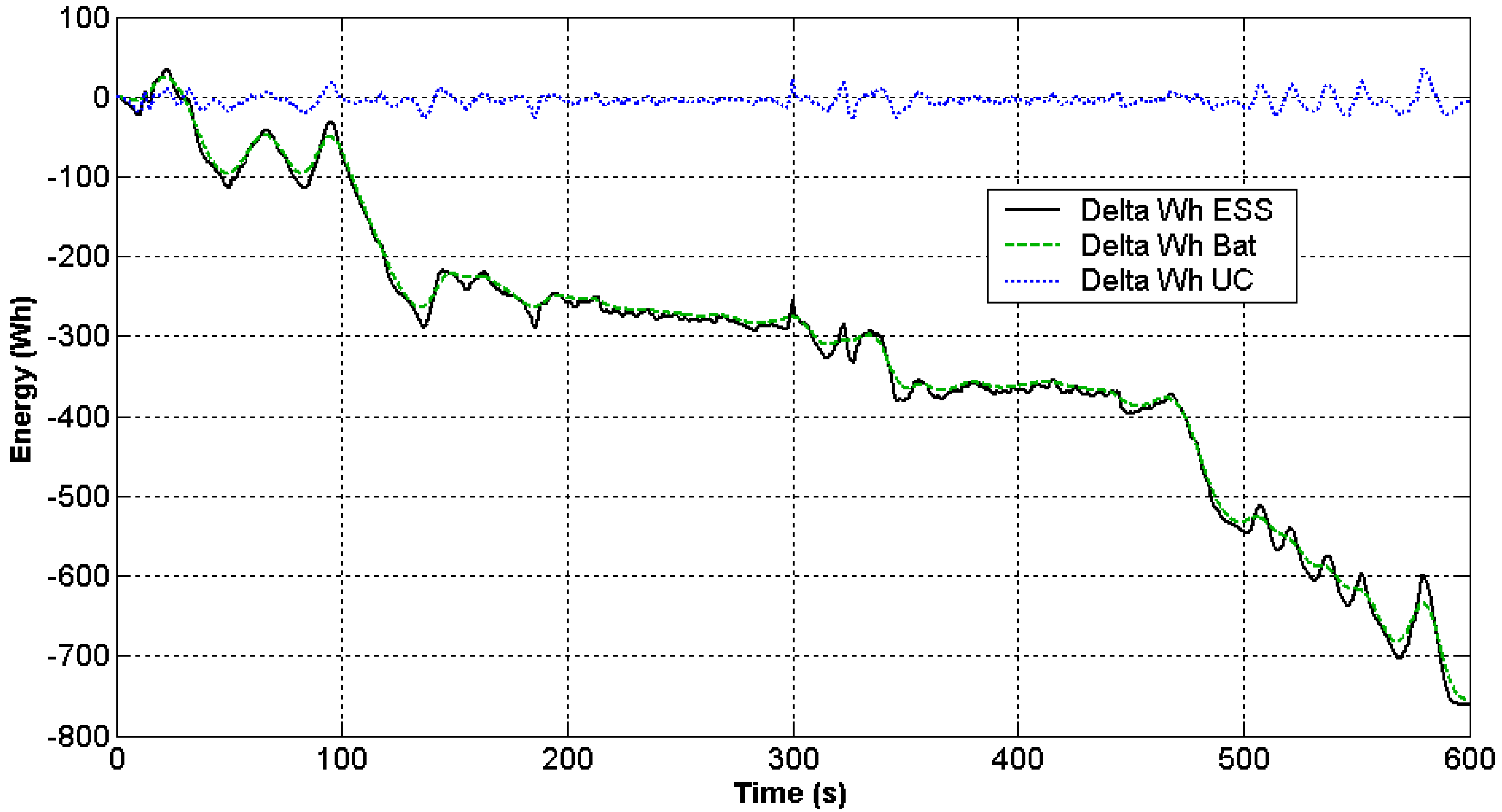


Example Case: Car during EPA's US06 Drive Cycle

- ICE: 60 kW, 20 s load average - (P_{fc20})
- Battery: 300 $V_{nominal}$, 1800 Wh, 30 kW P_{max}, 10 s load average - (P_{bat10})
- Ultracapacitor: 300 $V_{nominal}$, 94 Wh (900 F/cell), 50-100 kW P_{max}, Instantaneous Reaction



Example Case: Battery takes responsibility for net change in energy storage.



Conclusions

- Fuel Cell hybridization with EDLC's can provide benefit, but fuel cell downsizing is limited.
- Mild EDLC hybridization strategies need further evaluation versus batteries capabilities:
  - Regenerative energy recapture .
  - Fill in for fuel cell ramp rate.
  - Allow prime mover to operate at maximum efficiencies.
  - Traction assist; Transient suppressions.
  - Buffer fuel cell from high frequency switching harmonics.
  - Fuel cell start-up/shut-down loads.
- Matching power sources to appropriate loads should
  - Enable specialized, robust, and efficient components.
  - Reduce undesirable component stresses.
  - Improve operating points (efficiency, performance,…).
  - Improve thermal conditions.
  - Improve electrochemical balance in the battery.
  - Mitigate early failure modes.